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Bożena Denisow; University of Life Sciences in Lublin, Lublin, Poland; https://orcid.org/0000-0001-6718-7496

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ORIGINAL RESEARCH

Assessment of environmental performance on farms using FADN: A case study of the Region of Mazowsze and Podlasie, Poland

Alina Syp [1*], Dariusz Osuch [2], Anita Gębka[1]

[1]Department of Bioeconomy and Systems Analysis, Institute of Soil Science and Plant Cultivation - State Research Institute, Czartoryskich 8, 24-100 Puławy, Poland

[2]Agricultural Holdings Accountancy Department, Institute of Agricultural and Food Economics - National Research Institute, Świętokrzyska 20, 00-002 Warsaw, Poland

[*] To whom correspondence should be addressed. Email: asyp@iung.pulawy.pl

Abstract

Agri-environmental Schemes are the main agricultural policy instrument currently available in the European Union to help improve the relationship between agriculture and the environment. The conducted research included the assessment of AES (Agri-environmental Schemes) implementation in the Region of Mazowsze and Podlasie, Poland. This Region is characterized by worse natural, organizational, and production conditions than in other Regions in Poland. Out of the 292 analyzed farms, 146 formed the research sample, while another 146 constituted the control sample. In 2010 and 2014, all analyzed farms kept entries in accounting books under FADN (Farm Accountancy Data Network). All farms were classified according to TF8 as fieldcrops, milk, and mixed. For each type of farm, a research and control sample were distinguished. The research sample included farms that participated in the AES, whereas the control sample comprised farms that did not join the program. For each farm from the research sample, the most similar farm was selected in the control group, taking into account its type and location. The conducted study confirmed that the implementation of the AES has a positive effect on the environment, as it results in lower use of synthetic fertilizers, crop protection products, and GHG (greenhouse gas) emissions per ha. However, the research showed that the costs of reduction of GHG emissions are very high. In 2014, the cost of a decrease of 1 Mg CO_2 eq amounted to 1,302 PLN on fieldcrop farms, 611 PLN on milk farms, and 1,112 PLN on mixed farms. This is important information for policy makers, as it indicates that, while planning subsequent pro-environmental programs, it is crucial to perform a cost-benefit analysis and an *ex ante* assessment of the costs of planned activities in relation to the expected environmental effects.

Keywords

Agri-environmental Schemes; environmental assessment; farm; Farm Accountancy Data Network; GHG emissions; agricultural policy

1. Introduction

Agriculture is one of the oldest and most important human activities, which has been creating and transforming space since the beginning of its existence. However, the multidimensional anthropogenic activities lead to changes in the landscape, and very often wasteful economy contributes to the emergence of many environmental threats. Current production and consumption patterns have a negative impact on the environment because they contribute to climate change through greenhouse gas (GHG) emissions, water and air pollution, soil degradation, deforestation, as well as biodiversity loss (Bałuszyńska et al., 2022; Clark & Tilman, 2017; Sanyé-Mengual & Sala, 2022; Wąs et al., 2021). These impacts will probably intensify in the coming years

due to population growth and diet change by increasing meat consumption (Clark & Tilman, 2017). Solutions for reduction of agricultural environmental cost are increasingly better understood (Tanentzap et al., 2015). One of the main practical solutions to help protect and enhance the rural environment were Agri-environmental Schemes (AES) or their current successor: Agri-environment-climate Schemes (AECS) (which emphasize their role in climate action) (Ait Sidhoum et al., 2023; Batary et al., 2015; Bożek et al., 2023; Wąs et al., 2021). The AES was implemented as part of the Common Agricultural Policy (CAP) in the early 1990 as mandatory for all the European Union (EU) countries. However, farmers' participation in AES is voluntary. The AES differ greatly among countries and regions in the EU in order to reflect the complexity and regional diversity of both farming and eco-systems (Ait Sidhoum et al., 2023; Van Herzele et al., 2013). However, there are a number of overarching goals of all AES. The main ones are the habitat creation, biodiversity protection, pollution reduction, and support for extensive farming practices (McGurk et al., 2020). The AES have been a subject of many studies due to their great importance in achieving the objectives of the CAP (Ait Sidhoum et al., 2023; Bożek et al., 2023; Brown et al., 2019; Jachuła et al., 2022; Lastra-Bravo et al., 2015; Syp & Gębka, 2016; Uthes & Matzdorf, 2013; Wąs et al., 2021). For example, between 1994 and 2011, there were 419 publications on this subject in English in the Web of Science database (Uthes & Matzdorf, 2013). A significant increase in the number of papers dedicated to the AES occurred after 2001, when Agenda 2000 was implemented. On April 7, 2022, there were 3,080 papers in the Web of Science database, which were published between 1994 and 2022, with the highest number of 270 publications published in 2020. Most papers have a national or regional focus, addressing multiple factors that play a role in AES implementation (Wąs et al., 2021). A large group of articles examined either economic or ecological effects of AES operation (Uthes & Matzdorf, 2013). Other papers presented analyses on key factors influencing farmers' participation in the AES (Brown et al., 2019; Lastra-Bravo et al., 2015; McGurk et al., 2020; Van Herzele et al., 2013; Wąs et al., 2021). The analyses were based on field experiments, farm surveys, ecological-economic models, and experts' opinions. A few studies that address AES assessment used the Farm Accountancy Data Network (FADN) database (Gailhard & Bojnec, 2015; Wąs et al., 2021; Zimmermann & Britz, 2016). Gailhard and Bojnec (2015) and Wąs et al. (2021) identified factors determining farmers' participation in the AES based on farm size, production, and economic data. In turn, Zimmermann and Britz (2016) studied the relationship between AES participation and farming systems. The FADN is a European survey established in 1965, which collects accountancy data on annual basis from a sample of 80,000 commercial farms in the EU. The main aim of the FADN is to monitor the financial situation of agricultural holdings and to evaluate the impacts of the CAP. The Polish FADN database includes data from about 12,000 farms, which represent 749.6 thousand commercial farms. This is about 50% of all farms in Poland. However, they deliver around 94.6% of production to the market (Pawłowska-Tyszko et al., 2021). The FADN database is a unique and the most extensive element of the information system that facilitates a systematic and comprehensive analysis of various issues regarding internal mechanisms and cause-and-effect relationships determining the development of farms (Gołaś, 2002). The assessment of farms' sustainability in 28 EU countries has been performed based on FADN data by Dabkiene (2016), Dos Santos and Ahmad (2020), and Gerrard et al. (2012). The indicators they applied included e.g. the fertilizer and crop protection inputs per ha of utilizable agricultural area (UAA) and livestock unit (LU). In addition, based on FADN data, templates of nitrogen and phosphorus balances have been developed in Ireland (Buckley et al., 2015). FADN data was the basis for estimation of GHG emissions at the farm level in France (Corson et al., 2010), Italy (Coderoni et al., 2013; Coderoni & Esposti, 2018), Lithuania (Dabkienė et al., 2020), Greece (Tzouramani et al., 2020), Germany (Uthes et al., 2020), and Poland (Syp & Osuch, 2017, 2018). Coderoni et al. (2013) adapted and applied the Intergovernmental Panel on Climate Change (IPCC) methodology for estimating GHG emissions at the farm level. Using data from farms, they estimated nitrous oxide (N_2O), methane (CH_4), and carbon dioxide (CO_2) emissions in the following categories: livestock and crop productions, fertilizers, energy, and land use change. The system boundaries included only emissions related to the farm production phase on the farm. Therefore, emissions from the production of inputs

Table 1 Selected farm types based on FADN TF 8 grouping.

TF8	Description of TF8	Grouping of TF based on principal types of farming
1	Fieldcrops	Specialist cereals, oilseeds, and protein crops
		General field cropping
		Mixed cropping
5	Milk	Specialist dairying
8	Mixed	Mixed livestock, mainly grazing livestock
		Mixed livestock, mainly granivores
		Field crops – grazing livestock combined
		Various crops and livestock combined

Source: Pawłowska-Tyszko et al. (2021).

and the transport of food and feed products were not included. This approach makes it possible to analyze the GHG emissions of the individual farm at different levels. In addition, it gives the opportunity to compare the variability of GHG emissions between all types of farms due to their size and location all over the country and also at the European level. Furthermore, the use of FADN data makes it possible to link GHG emissions with other economic farm indicators to evaluate emission intensity at the farm level. According to Dick et al. (2008), the presented approach of calculation of GHG emissions at the farm level has two advantages. Firstly, it motivates farmers to apply best practices at every stage of production to reduce GHG emissions over which they have direct control. Secondly, it enables formulation of policies at the farm level in order to change farmers' input behavior. To the best of our knowledge, no one has used FADN data to assess GHG emissions from farms implementing the AES. Therefore, the aim of this paper is to measure the environmental performance of various types of farms participating in the AES in the Region of Mazowsze and Podlasie using FADN data. This paper will contribute to the literature on environmental assessment of farms at the regional level.

2. Material and methods

Data for the research come from the Polish FADN from the Institute of Agricultural and Food Economics - National Research Institute (IERiGŻ-PIB). For the purpose of this study, we investigated 292 farms which delivered data collected in 2010 and 2014 from the Region of Mazowsze and Podlasie. The analyses include the period of implementation of the AES program under the Rural Development Programme 2007–2013 (RDP). The territorial scope of the Region of Mazowsze and Podlasie covers the area of the Lubelskie, Łódzkie, Mazowieckie, and Podlaskie voivodships. From the 292 farms, a research sample of 146 farms and a control sample of 146 farms were distinguished. The research sample included farms that participated in the AES, whereas the control sample comprised farms that did not join the program. For each farm from the research sample, the most similar farm was selected in the control sample, taking into account the type of farm and its location. In the research and control samples, three farm types according to Type of Farming (TF8) grouping were selected, i.e., fieldcrops, milk, and mixed (Table 1).

To measure the environmental effect of the AES implementation, we applied a set of indicators presented in Table 2. The metrics indicators included both natural protection and biodiversity conservation issues which are applied to assess the protection of soils, groundwater, and production intensity. All costs were presented in fixed prices from 2010.

GHG emissions were estimated based on adoption of the IPCC methodology at the farm level using Polish emission factors presented in the official document of the National Centre for Emissions Management (KOBiZE) (Olecka et al., 2016) and data linked to the main farming activities coming from national statistics. To properly estimate GHG emissions at the farm gate, the IPCC methodology has been applied, which included GHG sources classified in two sectors, i.e. "Agriculture" and "Energy". The presented emission estimates do not include GHG emissions related to the "Land

Table 2 Assessment criteria used for all farms.

Environmental issue	Indicator
Natural protection and biodiversity conservation	Fertilizer and crop protection cost per 1 ha UAA (PLN)
	Farm GHG emissions by macro category (Mg CO_2 eq)
	Share of individual GHG emission categories (%)
	Emission intensity per 1 PLN of production value (kg CO_2 eq)
	Emission intensity per 1 ha UAA (kg CO_2 eq)
	Emission intensity per 1 LU* (kg CO_2 eq)
	Emission cost of 1 Mg CO_2 eq (PLN)

* LU – livestock unit.

Table 3 Description of GHG emissions based on FADN data and method for carbon footprint calculation (CF).

Emission sources	Emission category/method of CF calculation	FADN data
N_2O manure management	Animal production – Tier 2	Animal numbers
CH_4 manure management	Animal production – Tier 2	Animal numbers
CH_4 enteric fermentation	Animal production –Tier 1 – pigs; Tier 2 – cattle	Animal numbers
CO_2 Urea	Fertilizers – Tier 1	Quantity of urea applied
CO_2 Fuel	Energy – Tier 1	Quantity of fuel used
N_2O soil emissions		
N_2O direct emissions		
Inorganic N fertilizers use	Fertilizers – Tier 1	Quantity of N applied
Organic N fertilizers use	Fertilizers – Tier 1	Animal numbers
Crop residues	Crop production – Tier 1	Crop area
Urine and dung depositing by grazing animals	Crop production –Tier 1	Animal numbers
N_2O indirect emissions		
Atmospheric deposition	Fertilizers – Tier 1	Quantity of N applied / Animal numbers
Nitrogen leaching and run-off	Fertilizers – Tier 1	Quantity of N applied / Animal numbers/crop area

Source: Author elaboration based on Coderoni et al. (2013) and IPCC (2006).

Use, Land Use Change, and Forestry (LULUCF)" sector, as the FADN database has existed in Poland since 2004 and changes in carbon (C) content in the soil are estimated based on data covering a period of 20 years. An attempt to estimate changes in soil C content using available data would require many assumptions about agricultural practices. Based on farm data, CH_4, N_2O, and CO_2 emissions are estimated, broken down by source. In order to express the total emissions in CO_2 equivalents (eq), the emissions of the individual compounds (N_2O, CH_4 and CO_2) are multiplied by the Global Warming Potential (GWP) factors. The value of this indicator in a 100-year period is 1 for CO_2 and 298 and 25 for N_2O and CH_4, respectively (Forster et al., 2007). The sum of emissions in CO_2 equivalents is expressed as the farm's carbon footprint (CF). GHG emissions expressed in CO_2 eq were estimated for each type of farm in the research and control sample. Table 3 presents a summary of GHG emission sources, data used from the FADN, and the method of CF calculation. The method used does not take into account GHG emissions related to the production of agricultural inputs (e.g. fertilizers) and the transport of outputs (agricultural produce).

The cost of 1 Mg CO_2 eq emissions was estimated for each type of farm in the research and control sample. The calculation process included the following steps: at the beginning, the differences in GHG emissions between the control and research sample were calculated, then the AES payment was divided by the number obtained, which allowed estimation of the cost of 1 Mg CO_2 eq. Emission costs of 1 Mg CO_2 eq are expressed in fixed prices from 2010.

Table 4 Research and control samples in selected farm types in 2010 and 2014.

Variable	Farm types			Total
	Fieldcrops	Milk	Mixed	
Number of farms in research sample	68	21	57	146
Number of farms in control sample	68	21	57	146
Structure (%)	46.6	14.4	39.0	100

Table 5 Fertilizer and crop protection product costs per 1 ha in 2010.

Variable	Farm types								
	Fieldcrops			Milk			Mixed		
	Res.* ($PLN\ ha^{-1}$)	Contr.** ($PLN\ ha^{-1}$)	Diff*** (%)	Res.* ($PLN\ ha^{-1}$)	Contr.** ($PLN\ ha^{-1}$)	Diff*** (%)	Res.* ($PLN\ ha^{-1}$)	Contr.** ($PLN\ ha^{-1}$)	Diff*** (%)
Fertilizers	438	672	−35	232	409	−43	256	357	−28
Crop protection	192	339	−43	50	84	−40	87	125	−31

* Research sample, ** Control sample, *** Difference.

Table 6 Fertilizer and crop protection product costs per 1 ha in 2014.

Variable	Farm types								
	Fieldcrops			Milk			Mixed		
	Res.* ($PLN\ ha^{-1}$)	Contr.** ($PLN\ ha^{-1}$)	Diff*** (%)	Res.* ($PLN\ ha^{-1}$)	Contr.** ($PLN\ ha^{-1}$)	Diff*** (%)	Res.* ($PLN\ ha^{-1}$)	Contr.** ($PLN\ ha^{-1}$)	Diff*** (%)
Fertilizers	626	770	−19	367	571	−36	404	510	−21
Crop protection	242	333	−27	51	109	−53	124	174	−29

* Research sample, ** Control sample, *** Difference.

3. Results

The Region of Mazowsze and Podlasie covers an area of 99.1 km^2, which constitutes 31.6% of the area of Poland (GUS, 2015). The region is characterized by a large number of farms with (***i***) a small area of UAA, (***ii***) high rate of employment in agriculture, and (***iii***) extensive production, which results in low market production and profitability of farms. The results present data from the same 292 farms which both in 2010 and 2014 participated in the data collection in the FADN system. In each studied year, the research and control samples included 68 fieldcrops, 21 milk farms, and 57 mixed farms (Table 4). The number of agricultural holdings in the selected type of production varied, which shows that not all types of farms were interested to contribute to the AES.

In 2010 and 2014, in all types of farms implementing the AES, the expenditures on fertilizers and crop protection products were lower than on the control farms, which proves the use of smaller amounts of these inputs per ha (Table 5 and Table 6). In 2010, the costs of fertilizers and crop protection products per 1 ha in the milk research sample, compared to the control sample, were lower by 43 and 40%, respectively. In 2014, the differences in this type of farms were 36% for the fertilizer input and 53% for the crop protection products. In both study years, lower differences in those inputs were recorded on the fieldcrops and mixed farms.

In 2010 and 2014, all farms participating in the AES recorded lower GHG emissions than farms which did not participate in the program (Table 7 and Table 8). A comparison of the GHG emissions between the farm types in the control and research groups revealed the largest emissions from the milk farms, followed by the mixed and fieldcrops farms. In 2010, the GHG emissions from the control milk farms amounted to 130 $MgCO_2$, whereas on the research milk farms they were around 119 $MgCO_2$.

Table 7 GHG emissions at farm gates by macro category in 2010 (in Mg CO_2 eq farm^{-1}).

Emission category	Farm types											
	Fieldcrops				Milk				Mixed			
	Res*		Contr**		Res*		Contr**		Res*		Contr**	
	Mg CO_2 eq	%	Mg CO_2 eq	%	Mg CO_2 eq	%	Mg CO_2 eq	%	Mg CO_2 eq	%	Mg CO_2 eq	%
Animal production	8.5	18	6.2	10	77.8	65	85.2	66	21.6	50	30.8	57
Crop production	1.1	2	1.4	2	12.9	11	14.0	11	2.7	6	4.5	8
Fertilizers	24.2	52	39.7	66	19.8	17	22.0	17	12.3	28	13.3	24
Fuel	13.0	28	13.3	22	8.6	7	8.7	7	7.0	16	5.7	11
Total farm	46.7	100	60.6	100	119.1	100	130.0	100	43.6	100	54.3	100

* Research sample, ** Control sample.

Table 8 GHG emissions at farm gates by macro category in 2014 (in Mg CO_2 eq farm^{-1}).

Emission category	Farm types											
	Fieldcrops				Milk				Mixed			
	Res*		Contr**		Res*		Contr**		Res*		Contr**	
	Mg CO_2 eq	%	Mg CO_2 eq	%	Mg CO_2 eq	%	Mg CO_2 eq	%	Mg CO_2 eq	%	Mg CO_2 eq	%
Animal production	6.5	12	3.9	6	94.8	67	104.6	66	24.6	46	31.8	52
Crop production	1.0	2	1.1	2	15.0	11	16.6	11	3.2	6	4.7	8
Fertilizers	33.9	61	48.8	70	23.1	16	25.6	17	16.3	31	17.3	28
Fuel	13.9	25	15.4	22	8.4	6	10.1	7	8.9	17	6.9	11
Total farm	55.3	100	69.2	100	141.3	100	156.8	100	53.0	100	60.6	100

* Research sample, ** Control sample.

This result means that the GHG emissions from the research sample were lower by 9.2%. In 2104, this difference increased to 11%. On the fieldcrop farms, the differences in the GHG emissions were 30 and 25% in 2010 and 2014, respectively. The differences on the mixed farms were 25% in 2010 and 14% in 2014. In both study years, the GHG emissions in the research and control sample of the fieldcrops and mixed farms were over two-fold lower than the GHG emissions from the milk farms. The differences in the GHG emissions are a consequence of farm specialization. Livestock production is a branch of agriculture that emits the most GHG into the environment. In our study, the GHG emissions from animal production on the milk farm accounted for over 66% in the total GHG farm emission, and this value was almost the same for the research and control samples. The share of GHG emission from animal production in the total GHG farm emission was slightly lower in the group of the mixed farms. Another source of significant GHG emissions into the environment is fertilizers, followed by the fuels used. In 2010, the GHG emissions from the application of fertilizers on the fieldcrops farms constituted 52 and 66% of the total GHG emissions in the research and control sample, respectively. In 2014, the GHG emissions in this type of farms increased to 61% for the research group and 70% for the control farms. In both study years, the GHG emissions from the fuels used were higher in the research group of fieldcrops and mixed farms compared to the control farms.

The lower GHG emissions from the AES beneficiary farms resulted in lower emission intensity in terms of 1 PLN production value, 1 ha UAA, and 1 LU compared to the control farms (Table 9 and Table 10). In 2010, the fieldcrops and milk farms participating in the AES were characterized by higher GHG emissions per 1 PLN of production value than farms that did not participate in the program. The difference was 20% and 11% for the fieldcrops and milk farms, respectively. In the mixed farms participating in the AES, the GHG emission intensity per 1 PLN was 20% lower than in the control group. In 2014, the fieldcrops and mixed research farms recorded lower GHG emissions per 1 PLN of production value than the control farms. However, they were higher than in 2010. In 2014, only the research milk farms participating in the AES were characterized by higher GHG emissions per 1 PLN of production value,

Table 9 GHG emission intensity at the farm level in 2010, in kg CO_2 eq.

Specification	Farm types								
	Fieldcrops			Milk			Mixed		
	Res.*	Contr.**	Diff.***	Res.*	Contr.**	Diff***	Res.*	Contr.**	Diff***
Emission intensity per 1 PLN value of production	0.31	0.26	20	0.91	0.82	11	0.42	0.52	−20
Emission intensity per 1 ha UAA	1,128	1,282	−12	3,780	4,975	−24	1,957	2,530	−23
Emission intensity per 1 LU	4,462	11,897	−63	4,317	4,359	−1	2,292	2,936	−22

* Research sample, ** Control sample, *** Difference in %.

Table 10 GHG emission intensity at farm level in 2014, in kg CO_2 eq.

Specification	Farm types								
	Fieldcrops			Milk			Mixed		
	Res.*	Contr.**	Diff.***	Res.*	Contr.**	Diff***	Res.*	Contr.**	Diff***
Emission intensity per 1 PLN value of production	0.34	0.35	−3	0.89	0.82	9	0.49	0.53	−8
Emission intensity per 1 ha UAA	1,214	1,445	−16	4,033	5,801	−31	2,069	2,501	−17
Emission intensity per 1 LU	6,496	22,066	−71	4,593	4,608	−0.3	2,757	3,397	−19

* Research sample, ** Control sample, *** Difference in %.

Table 11 Cost of 1 Mg CO_2 eq GHG emissions at the farm level in 2010, in PLN.

Specification	Measurement units	Farm types		
		Fieldcrops	Milk	Mixed
Difference in GHG emissions between control and research farms	Mg CO_2 eq	13.8	10.9	10.7
AES payment	PLN	13,122	7,989	7,812
Cost of emission of 1 Mg CO_2 eq	PLN Mg CO_2 eq^{-1}	951	733	730

Table 12 Cost of 1 Mg CO_2 eq GHG emissions at farms level in 2014, in PLN.

Specification	Measurement units	Farm types		
		Fieldcrops	Milk	Mixed
Difference in GHG emissions between control and research farms	Mg CO_2 eq	13.9	15.5	7.6
AES payment	PLN	18,098	9,470	8,452
Cost of emission of 1 Mg CO_2 eq	PLN Mg CO_2 eq^{-1}	1,302	611	1,112

but this value was lower than in 2010. The differences in the emission intensity per 1 ha UAA between the control and research farms were higher than GHG emissions per 1 PLN value of production. In 2010, the differences were 24, 23, and 12% for the milk, mixed, and fieldcrop farms, respectively. In 2014, the difference grew to 31 and 16% for the milk and fieldcrop farms and decreased to 17% for the mixed farms. The lower values of the GHG emission intensity per 1 ha UAA were the consequence of the lower production of these farms, which confirms that the implementation of the AES contributes to the extensification of production. In both study years, the difference in the emission intensity per 1 LU between the research and control milk farms was very small. This result indicates that the implementation of the AES in this type of farms does not bring the expected environmental benefits.

In 2010 and 2014, the reduction cost of 1 Mg CO_2 eq emissions varied depending on the type of farm (Table 11 and Table 12). On the fieldcrop farms, the reduction cost in 2010 was 951 PLN, but increased by 37% to 1,302 PLN in 2014. In 2010, the reduction cost on the milk and mixed farms was at a similar level of 730 PLN. In 2014, the price of reduction of emissions on the mixed farms increased by 52% to 1,112 PLN, and decreased by 20% to 611 PLN on the milk farms. In both analyzed years, the costs

Table 13 Average price of emission allowance for 1 Mg CO_2 eq in 2010–2014, in € and PLN.

Specification	Year				
	2010	2011	2012	2013	2014
Average price of emission allowances for 1 Mg CO_2 eq in €	14.8	12.9	7.4	4.3	6.0
Average price of emission allowances for 1 Mg CO_2 eq in PLN	59.0	53.2	31.0	18.1	25.2

Source: authors elaboration based on data Emission of CO_2 – archive – investing.com (2022) and average NBP rate.

of reducing emissions by 1 Mg CO_2 eq on the farms compared to the market prices of CO_2 emission allowances (EUAs) were higher (Table 13). From 2010 to 2012, a decrease in the market prices of CO_2 emission allowances was recorded. It was due to a large number of free emission allowances granted to member states between 2005 and 2012 on the basis of overestimated emission forecasts (Zborowska & Dombrowicki, 2014). Starting from 2013, there has been a reduction in the number of allocated allowances and an increase in their prices. In 2018, the value of 1 Mg CO_2 eq emissions was 77.2 PLN, whereas in 2021 it increased to 253 PLN (*Emisja CO_2 - archiwum notowań - Investing.com [CO_2 emissions – archive – Investing.com]*, 2022; https://pl.investing.com/commodities/carbon-emissions-historical-data). These figures are much lower than the cost of reducing 1 Mg of CO_2 eq on the analyzed farms.

4. Discussion

The present study showed differences between the cost of fertilizers and crop protection products per ha. All research farms recorded lower expenditure for those inputs. The largest differences in both costs in the analyzed years were observed for the milk farms, whereas the lowest differences were noted for the mixed farms. The obtained results indicate that the implementation of the AES program has a positive impact on the environment because of the lower inputs per ha UAA compared to other farms. The lower fertilizer input resulted in lower GHG emissions from all research farms. However, the lower per-ha use of fertilizer and crop protection products required additional maintenance treatments on these farms, which was associated with higher fuel consumption. Despite these additional fuel inputs, the GHG emissions from the research farms were lower compared to the control farms. Similar results were obtained in studies by Syp and Osuch (2018) and Coderoni and Esposti (2018). In 2014, compared to 2010, all farms recorded an increase in GHG emissions. These results are the effect of increased production in each of the surveyed groups of farms. The same trend was observed in Italy, where production expansion across all farm types between 2003 and 2007 resulted in higher GHG emissions (Coderoni & Esposti, 2018). These results indicate that agricultural activities carried out on AES-implementing farms had a lower negative impact on the environment compared to farms that did not participate in the program. Our analyses show that larger environmental benefits are achieved through conversion from conventional agriculture systems to alternative ones. This is in agreement with research results reported by Clark and Tilman (2017). As shown by Korotkova et al. (2021), on all farms, the negative impact of the use of fertilizers and crop protection products could be reduced by application of humic substances.

The costs of GHG emission reduction on the studied farms were very high. Therefore, the data presented in the study raise questions about the efficiency of the funds spent. Similar doubts about the efficiency of the use of public funds were presented by Ait Sidhoum et al. (2023) and Batary et al. (2015).

5. Conclusion

To address the sustainability of the agricultural sector, the EU has allocated a large share of the Common Agricultural Policy (CAP) to the AES, which play a key role in promoting the provision of environmental public goods such as management of natural resources, biodiversity protection, and climate change mitigation. Mitigation of GHG emissions is becoming an increasingly important issue in the agricultural sector since agriculture is a significant contributor to climate change. GHG emissions

from agriculture represent nearly 50% of global anthropogenic CH_4 and 75% of the total NO_2 (Tubiello et al., 2022). The European Green Deal aims to reduce GHG emission to zero by 2050. It is important for the amount of GHG to be reduced but also for the process to be performed in a cost-effective way. In some cases, savings may be made relatively easily at minimum (or even no) cost. In other cases, savings may probably be expensive. Therefore, as suggested by Dick et al. (2008), improvement of the measurement of farm scale emissions should be accompanied by attempts to improve the understanding of the cost of mitigation.

The paper contributes to the literature on farms' participation in the AES by providing calculation of GHG emissions at the farm level. Coderoni et al. (2013) found that a methodology based on the FADN could allow an integrated assessment of GHG mitigation in a cost-effective manner, as FADN data are collected for economic analysis.

Our study provides the first analysis of environmental farms' performance for the Region of Mazowsze and Podlasie applying FADN data. We focus on assessment of the impact of participation in the AES in relation to production activities for fieldcrops, milk, and mixed farms. The analysis is based on FADN single farm data for 2010 and 2014. The conducted study confirmed that the implementation of the AES has a positive effect on the environment, as it results in a lower use of synthetic fertilizers, crop protection products, and GHG (greenhouse gas) emissions per ha. However, the research showed that the costs of GHG emission reduction in agriculture are very high compared to the market prices of CO_2 emission allowances. The study shows that, in planning subsequent pro-environmental programs, a cost-benefit analysis (CBA) and an *ex-ante* evaluation of the costs of planned activities in relation to the expected environmental effects are essential. In addition, the proposed methodology constitutes the basis for further research.

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